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Versatile PC-Based Data Acquisition and Control System Automation of EPA's (Environmental Protection Agency's) Air Toxics Control Laboratory

Acurex Corp., Research Triangle Park, NC

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16. ABSTRACT

The paper discusses the decision making process which resulted in the selection and configuration of the hardware and software for the Air Toxics Control Laboratory (ATCL) designed and built at EPA's Air and Energy Engineering Research Laboratory, in response to the need for the evaluation of volatile organic compounds (VOCs) and hazardous air pollutants (HAPs) from commercial and industrial operations. The ATCL was designed to allow the investigation of a wide variety of control technologies. The equipment needed to perform these investigations varies widely. The first technology selected to be tested was adsorption using activated carbon. This technology directed most of the design decisions. A description of the automated facility and its operation is included.

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Data Acquisition	Stationary Sources	14B
Data Processing	Air Toxics	09B
Adsorption		14G
Organic Compounds		07C
Toxicity		06T

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VERSATILE PC-BASED DATA ACQUISITION AND CONTROL SYSTEM: AUTOMATION OF EPA'S AIR TOXICS CONTROL LABORATORY

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INTRODUCTION

An Air Toxics Control Laboratory (ATCL) has been designed and built at the Environmental Protection Agency's (EPA's) Air and Energy Engineering Research Laboratory (AEERL) in response to the need for the evaluation of volatile organic compounds (VOCs) and hazardous air pollutants (HAPs) from commercial and industrial operations. This laboratory was designed to allow the investigation of a wide variety of control technologies. The equipment needed to perform these investigations varies widely. The first technology selected to be tested was adsorption using activated carbon. This technology directed the majority of the design decisions.

Every attempt was made to consider reasonable facility constraints. The facility size was dictated by available space and projected operating expense. Relatively long tests were projected, so some form of automation was a necessity.

Personal computers (PCs) have become a major component in automating research laboratories. Early in the design, it was determined that the PC-based control system was a viable choice for this facility. The selected equipment had to be available "off the shelf." The wide variety of equipment available hardly made this a limiting factor. Agreeing where to limit the options, largely a budget issue, was the biggest problem encountered.

BACKGROUND

Volatile organic compounds (VOCs) and hazardous air pollutants (HAPs) emitted from commercial and industrial operations are a serious threat to health and environment. Many of them cause destruction of the stratospheric ozone layer, others can be precursors of ozone production in the troposphere, while others may be carcinogenic. The Air Toxics Control Laboratory (ATCL) was conceived as a means for evaluating technologies to control the emission of these substances. Techniques for controlling the emission of these materials include carbon adsorption, catalytic oxidation, incineration, and emerging novel approaches such as corona destruction and pulse energization. During 1985, adsorption was chosen as the first control technology to be tested.

DESIGN CRITERIA

The Air Toxics Control Laboratory design addressed several key parameters:[1]

- A clean air stream which can be spiked with known compounds to produce the required challenge stream.
- Stable flow, temperature, and moisture content of the challenge streams.
- Steam regeneration followed by hot gas drying and bed cooling to prepare the

bed for future cycles.

- Multiple components in the challenge stream.
- Automatic operation rather than manual control.
- Automatic collection of process and analytical data.
- Future expansion/modification of the system with minimal capital outlay.

The design criteria developed for this facility are listed in Table I. Several of the parameters in this table may be controlled beyond the specified ranges to provide flexibility for future research areas. These extended ranges are listed in Table II.

TABLE I: Design Criteria

Process Air Flow	4 to 50 Nm^3/h
Process Air Temperature	27 to 57 °C
Regeneration Air Flow	3.4 to 25 Nm^3/h
Regeneration Nitrogen Flow	3.4 to 25 Nm^3/h
Steam Flow	1 to 7 kg/h
Regeneration Air Temperature	25 to 260 °C
Regeneration Nitrogen Temperature	25 to 260 °C
Adsorber Bed	15.2 cm dia. x 74 cm long
Humidity	20 to 80% RH

TABLE II: Process Extended Setpoint Capability

Process Air Flow	100 Nm^3/h Max
Process Air Temperature	120 °C Max
Regeneration Air Flow	45 Nm^3/h Max (Note 1)
Regeneration Nitrogen Flow	45 Nm^3/h Max (Note 1)
Steam Flow	25 kg/h (Note 2)
Adsorber Bed	limited only by space

Note 1 - The 1.5 cm regeneration piping will allow flows to be approximately 85 Nm^3/h. These higher flows require recalibration or replacement of the mass flow transmitter.

Note 2 - The steam generator will supply up to 80 kg/hr of steam at 140 kPa. This requires that it be rewired for 460 VAC 3-phase as opposed to the 208 VAC 3-phase currently installed. The flowmeter is capable of measuring 25 kg/hr steam flow. The steam piping may have to be increased in size to accommodate >25 kg/hr and the flowmeter replaced for higher flow operation.

As part of the design process, it was determined that the automatic data acquisition be as flexible as possible. The concept of automation prompted the idea of a computerized laboratory, in which its operation and data acquisition should perform automatically with minimum operator intervention. From the analytical perspective, the use of Labtech Notebook for gas chromatograph (GC) and total hydrocarbon (THC) system control and data acquisition reduces the need for process control programming experience. This also maximizes the operator's ability to acquire meaningful data with a minimum time investment. The process control program is written in Microsoft QuickBASIC™. Every attempt was made to keep this large program (approximately 2400 lines of code) as modular as possible to allow for future modifications or expansion of the program.

Several components (including a computer, software, and controllers) were necessary to accomplish automatic laboratory operation and data acquisition. Personal computers were selected as the foundation of the data acquisition system for several reasons. First, the number of data points saved for each parameter during the operation of the facility was too great to be handled by manual collection. Second, PCs are rapidly becoming the dominant force in data acquisition applications. They are powerful enough to relieve minicomputers and mainframe computers from many time consuming tasks, and sufficient quality hardware has become available to make their selection worthwhile. Third, most of the PCs used for data acquisition are desktop computers such as IBM PCs and compatibles. Many people are already familiar with their operation, and many software packages already exist for data reduction. Forth, and most important, PCs are extremely cost effective for data acquisition. Nevertheless, a PC alone is not a data acquisition system. There must be hardware and software products to gather and preprocess the analog data for digital input to the PC.

Due to the large number of devices to be turned on and off and analog points that require acquisition, it was determined that a hard wire system involving relays and timers would not be acceptable. Such a system would also severely limit future expansion or modification of the facility.

The focus of considerations then went toward programmable logic controllers (PLCs) and computers. Since the data to be acquired were largely dependent on the specific operating modes of the process facility, a high level of integration would be required between data acquisition and process control.

When considering a PLC, analog input and data storage are severely limited. PLCs are better suited to industrial control applications where changes are seldom made,

rather than research laboratories where the direction of the research could dictate changes in the configuration of the facility at almost any time.

Several different manufacturers of PLCs offer systems that would probably be able to handle all of the on/off operations, the closed-loop control, and the data acquisition. However, with the ready availability of add-in cards and chassises for personal computers, a personal computer is a very viable solution for research installations such as the one discussed in this paper.

Since the design was for a laboratory environment rather than a factory floor, the ruggedness of a PLC was not an issue. On cost-benefit analysis, the PC with appropriate data acquisition interface is a more cost-effective solution than a PLC.

When control loops are included as part of the data acquisition system design, there is a tendency to underestimate hardware and software requirements. Implementing proportional integral differential (PID) control loops requires considerable central processing unit (CPU) time. It was decided to use separate PID controllers for closed-loop control. Controllers were selected that accept external setpoint input. This allows the computer data acquisition system to maintain the ability to modulate process variables, while eliminating the overhead associated with implementing PID loops in software.

Two types of process variable transmitters are used in the design. Dual-output transmitters are used to send separate signals to the controllers and data acquisition system. These transmitters allow the data acquisition system access to the process variables, at the same moment they are sent to the controllers. This offers a measure of redundancy, while maintaining the process control system's safety and interlock capability over the facility. Variations in calibration are handled by changing calibration constants in the process control software.

The selection of process control software became relatively simple. It was decided to hardcode the system with a high level language. Of the available high level languages (BASIC, C, Forth, etc.), BASIC was chosen for this system. Since BASIC programmers were available on staff, it was a simple decision to write the control program in this language.

Since this facility operates at relatively steady state conditions and PID control loops are not part of the control program, extremely fast cycle time was not required. An IBM PC/AT was selected as the base for the data acquisition control system. The

control program itself was written in QuickBASIC. The original program was written in QuickBASIC 2.0 and later updated and rewritten in QuickBASIC 4.0.

FACILITY DESCRIPTION

Process Air Supply

An Atlas Copco screw type air compressor generates up to 136 m^3/h air flow at 827 kPa and up to 60 °C. This compressor is equipped with dual control to allow compressor shutdown in the event that demand for air has ceased for at least 5 minutes. On a drop in air pressure to the lower setpoint, the compressor will restart. While there is a demand for air, the compressor will maintain the air pressure between 586 and 827 kPa. The clean air system is schematically shown in Fig. 1.

A liquid separator removes gross oil and water droplets, but the fairly high outlet temperature precludes much moisture removal at the compressor. The bulk of water and oil are removed by the external Airtek air cooled aftercooler. This device is sized to reduce the temperature of the air at maximum flow output of the compressor to within -15 °C of the ambient dry bulb temperature. An extremely efficient droplet separator removes most of the water and oil at the cooler's outlet. A float type trap keeps the separator drained.

Following the separator are two coalescing filters rated at 0.1 µm. They are equipped with auto-drain traps that limit passage of oil farther down the line. The outlet of the filters is connected to a 456-liter capacity air tank. This tank has sufficient volume to maintain air flow and pressure to operate the valves for shutdown. The outlet of the tank is connected to a Zurn Industries regenerative air dryer. Integral controls alternate the air stream between two desiccant towers to provide -40 °C dew point air. The assembly also includes very high efficiency coalescing filters and a 68 kg capacity carbon tank for removing non-methane hydrocarbons.

The clean air is delivered to the conditioning portion of the test facility and the regeneration system, and is used for process control motive force.

Water Purification System

The organic free water used for challenge stream humidification and for regeneration steam is provided by a Dracor-supplied, combined reverse osmosis and deionization system. A 38-liter capacity storage tank maintains a supply of water for the steam generator to use during regeneration cycles.

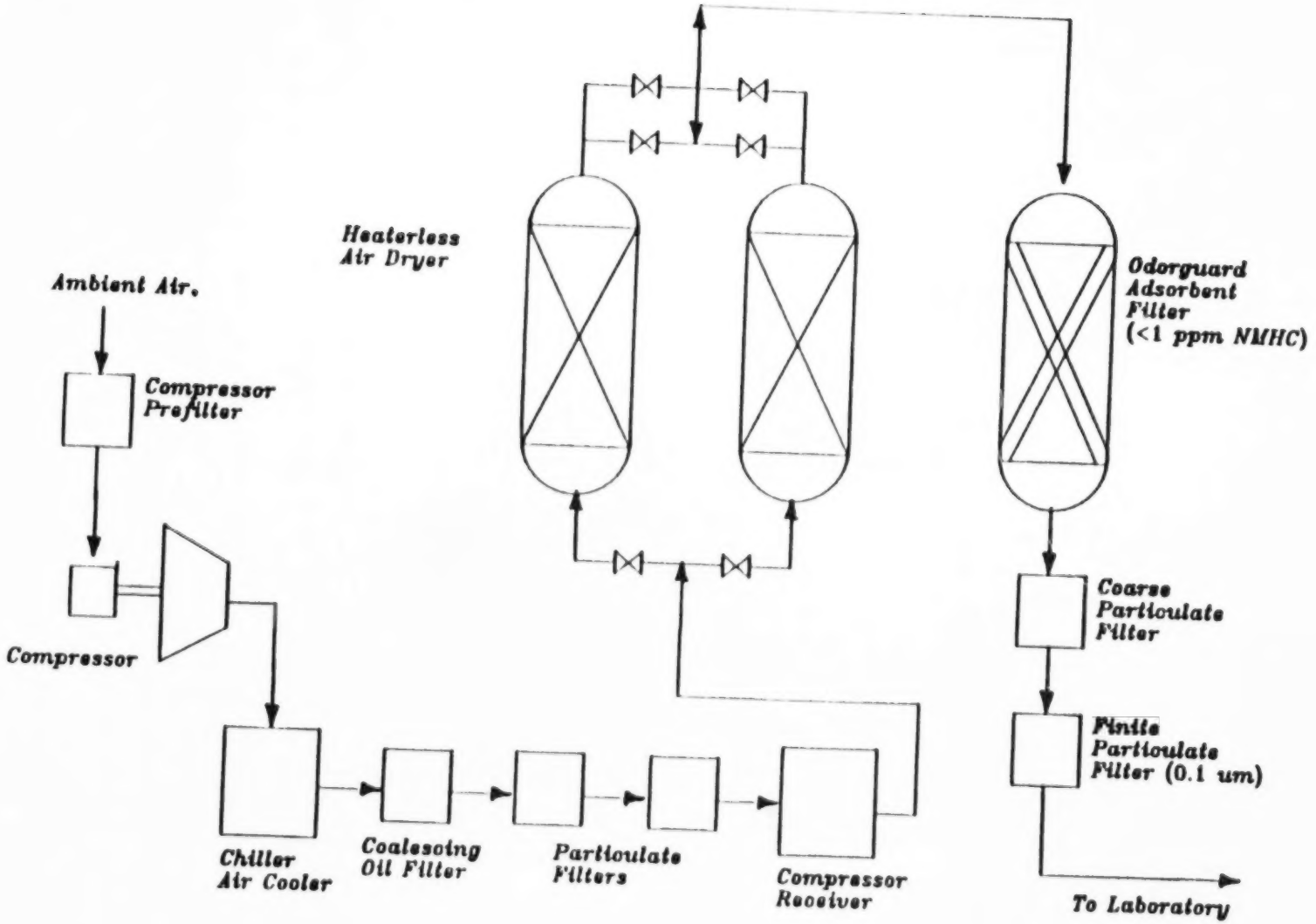

Fig. 1. Clean air system.

Steam Generator

Regeneration steam is provided by an Electro Steam Corporation steam generator, and water from the reverse osmosis system storage tank is fed to the generator. Up to 140 kPa steam with reduced organic content is made available for adsorber bed regeneration. A Validyne pressure transmitter and FMCI flow transducer and transmitter send readings to the data acquisition system.

Challenge Stream Conditioning

The conditioning system prepares the challenge stream for presentation to the adsorbers. First the stream passes through a Fairchild precision air pressure regulator. This regulator is capable of maintaining the stream pressure within ±15 cm of water column at flows of 135 Nm^3/h. The regulator is followed by a check valve to prevent back flow due to accidental system upsets. A Bauman, linear plug, flow control valve maintains the selected challenge stream flow rate. This valve has a pneumatic proportional operator which is modulated by a Doric series 7000 auto-tuning controller, through a Bellowfram type 100 current to pneumatic transducer. The challenge stream flow is measured by a Kurz Instruments mass flow transducer/transmitter. This flow transducer is located in the process piping downstream of the humidifier and the VOC injection point. After the flow control valve, the challenge stream is heated.

The challenge stream is heated by a Hotwatt Inc. electric heater. The temperature control sensing element is located downstream just after the flow sensor and prior to the adsorbers. This allows the heater to be modulated providing additional heat to overcome pipe heat losses as well as heat of vaporization required for the injected VOCs.

At the outlet of the air heater, the humidifier delivers the required moisture for air stream humidification (see Fig. 2). This humidifier is constructed from a Watlow 6 kW electric circulation heater. The heater is controlled at 230 to 290 °C. Water is delivered to the heater from a polycarbonate reservoir by a Perkin Elmer HPLC pump. A 122 cm static mixing section blends the heated air and vapor from the humidifier.

A general Eastern 1200AP humidity sensor and transmitter are located at the outlet of the mixing section to quantify the moisture content of the challenge stream.

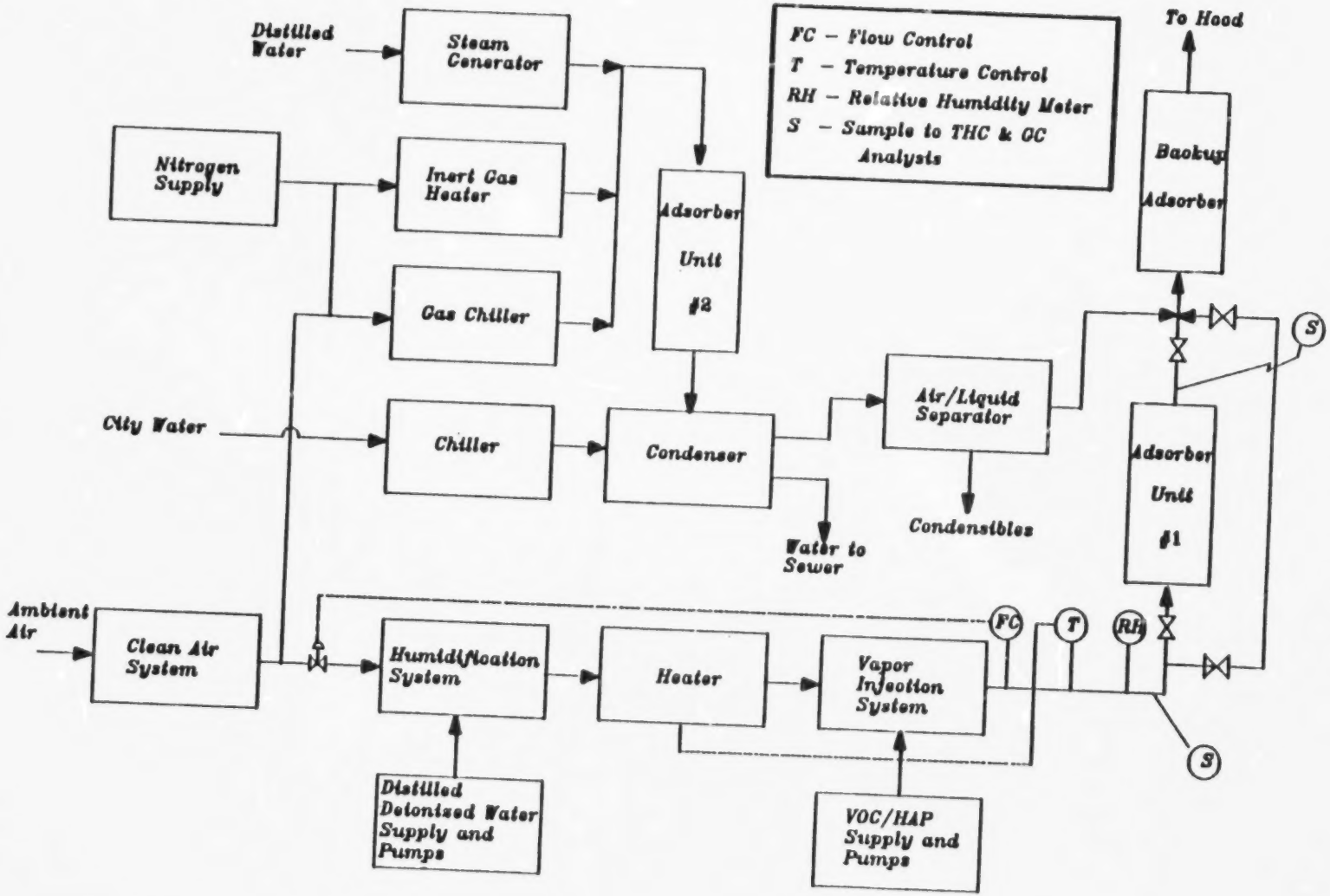

Fig. 2. The adsorption system.

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This freezing mirror type sensor measures humidity, one of the primary test parameters under study.

The selected VOC is injected into the challenge stream by a second Perkin Elmer HPLC pump. The pump, activated by the process control program, meters the VOC to a Sprayco ultrasonic nozzle. This nozzle disperses the VOC into the challenge stream.

The challenge stream is now ready for presentation to the selected adsorber bed at known flow and temperature, with metered VOC concentration (primary process variable) and metered moisture (secondary process variable).

Adsorbers

The two adsorbers are designed to allow a 50.8 by 15.2 cm column of adsorber material or materials to be loaded for testing (see Fig. 3). Valving is provided to bypass both adsorbers or to challenge one adsorber while simultaneously regenerating the other. Inlet pressure and temperature readings are measured at each adsorber as well as the adsorber differential pressure and outlet temperature. The organic concentration of the inlet challenge stream is sampled at a point common to both adsorbers. Notwithstanding, the outlets of the adsorbers are individually sampled.

A backup adsorber filled with 135 kg of activated carbon completes the adsorber section and the challenge stream path. The backup adsorber prevents release of test components into the atmosphere.

Regeneration System

There are three regeneration modes available: steam stripping, nitrogen purge, and air purge. All three modes are available during the regeneration cycle. Steam for stripping is provided by the Electro Steam steam generator. Valving routes the steam, nitrogen, or air through the desired bed and out to the condensers. Either nitrogen or air can be heated up to 235 °C or cooled to approximately 4.5 °C. The sequence, flow rates, and temperatures of the regeneration mode are selected at start-up by the process control program.

The outlet of the adsorbers during regeneration is routed to two energy shell and tube heat exchangers mounted in series. The first exchanger is cooled by house water. The second exchanger is supplied with 4.5 °C water by a Remcor water chiller. The

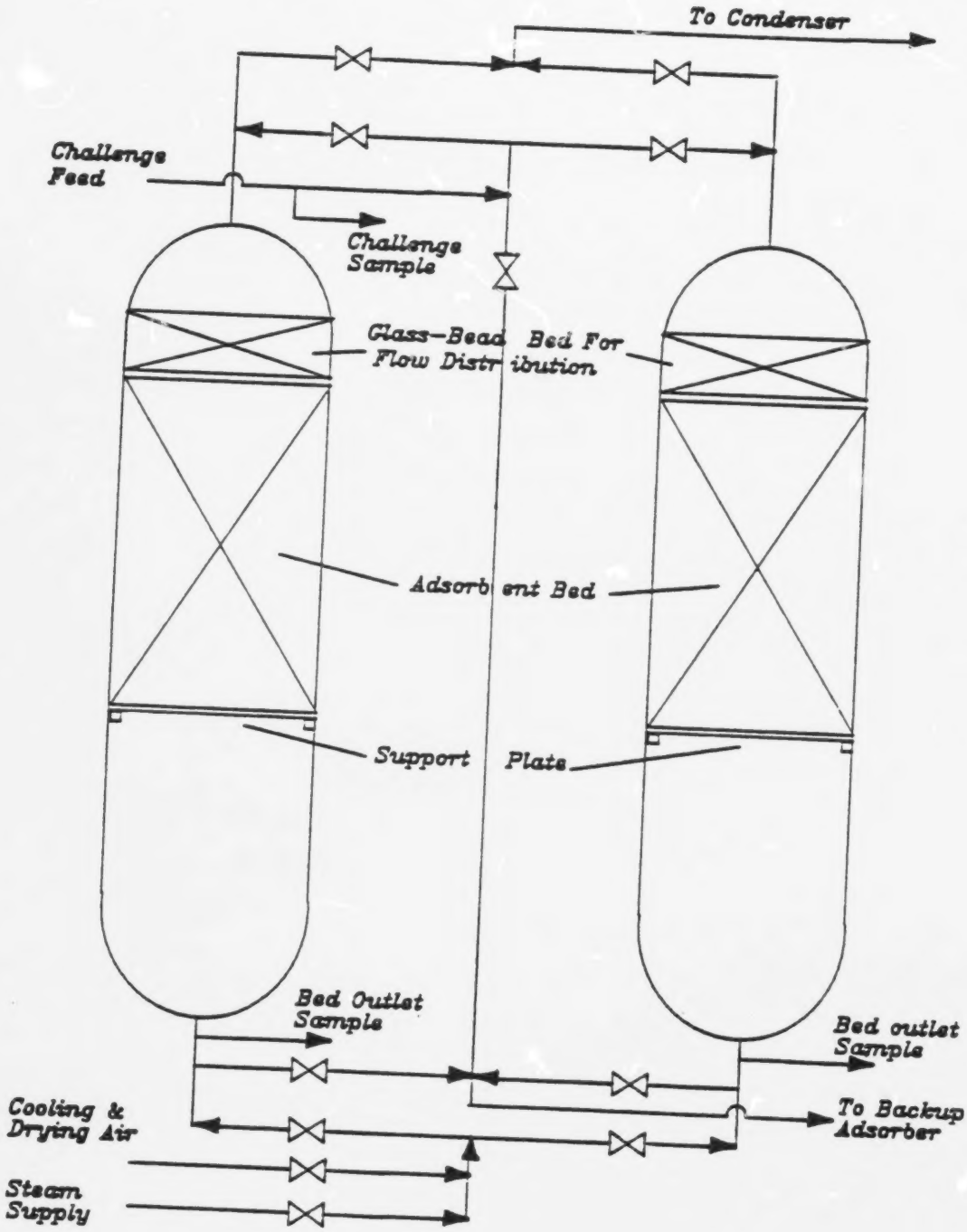

Fig. 3. The adsorbers.

exchanger outlet is routed to a Balston coalescing filter where it is condensed, and the captured liquid is drained to a glass bottle for disposal.

Controls

The majority of the system controls are located at the control console. At the top of the console are indicator lights for major pieces of facility equipment and process events. Located just above the indicators are alarm lights. The alarm lights are activated at the same time that the process control computer is signaled. The alarm event is noted on the process control computer monitor and is written into the alarm file.

The control system selected for the ATCL is based on OPTO-22 process control and data acquisition components. These add-on chassises and modules interface through a standard data port RS-422 in an IBM-PC/AT computer (see Fig. 4). The IBM computer, through operator interaction, stores the setpoint parameters for operation. Then, it executes the control program that processes acquired data in real time. Thereby, it also allows the operator to interface with the process and displays the key process parameters during a test. Start-up and shutdown sequences and communication with the digital and analog input/output modules are handled by the LC-2.

Process variables requiring closed loop control are modulated by six Doric model 7000 auto-tuning PID controllers. At the operator's discretion, the Doric controllers will operate from a local setpoint or accept a setpoint provided by the computer control system. Separate process variable input is transmitted to the process data acquisition system that maintains safety interlock and override (shutdown) capability over the process variables in either control mode.

Separate displays for system temperatures of interest for process performance monitoring are available at the bottom of the control console. It is anticipated that connections to these displays will vary with individual tests and as experience with the facility dictates.

In an effort to ensure that control of an errant process can be regained, the controllers selected have provision for manual override of the automatic setpoint. The control program also has shutdown provisions and time-out interlock in case of computer lockup.

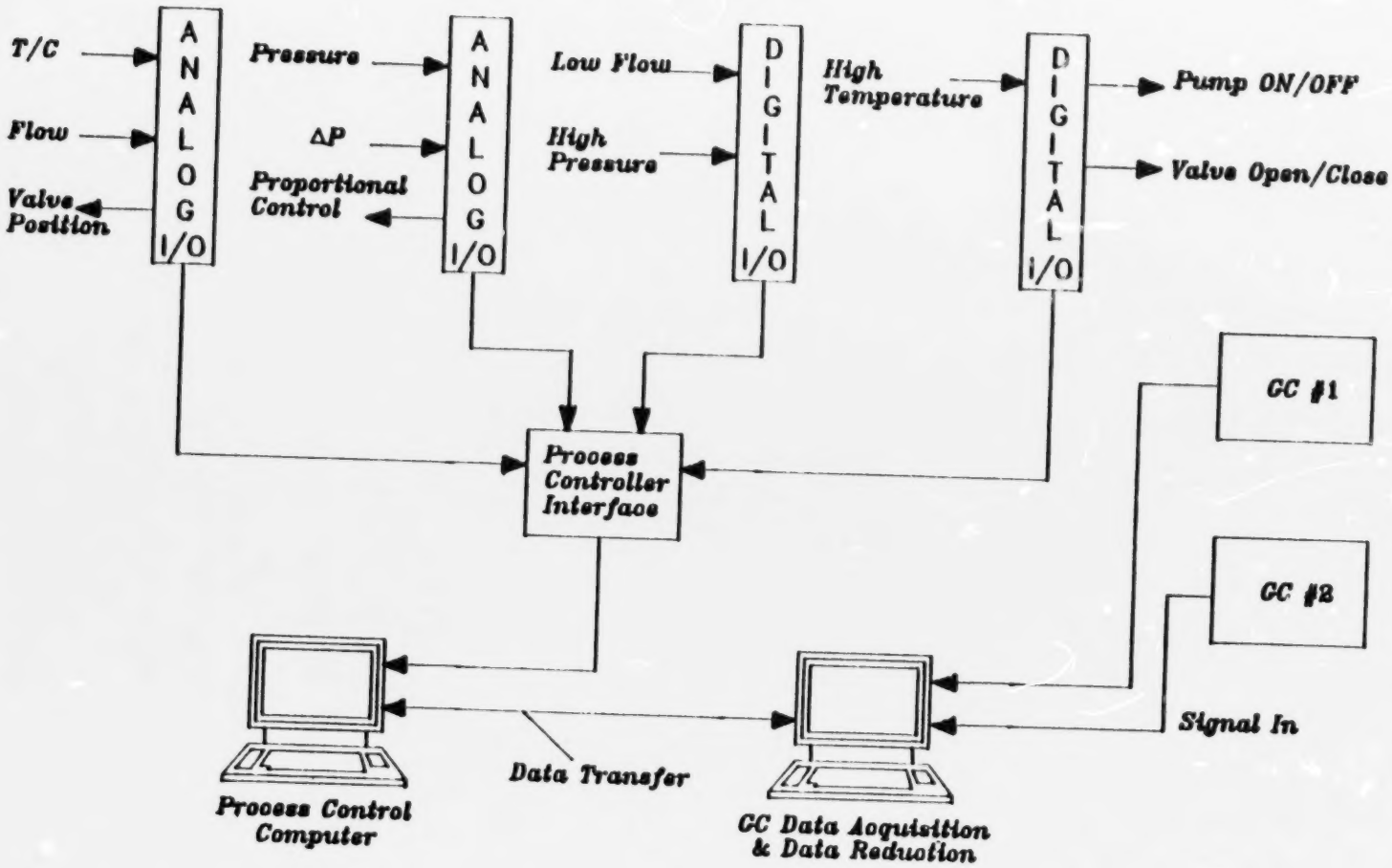

Fig. 4. VOC/HAP Control system.

The process control system is integrated with an analytical data acquisition and control system. The analytical system consists of an HP model 5890 GC and a Shimadzu Mini-2 GC configured for total hydrocarbon operation. The HP GC operates under the control of an IBM-PC with a Metrabyte Dash 16 data acquisition card. An interface with the process control system ensures that the GC system samples only an adsorber if in challenge mode. The sampling sequence is programmable on the GC control computer. The control program used is Labtech Notebook which facilitates the handling of input signals and the control of GC valves. Additional software is written to manipulate the acquired data. Analytical and process data are reduced by Labtech Chrom and Lotus 1-2-3.

INTERFACING AND OPERATING PROBLEMS

In any research laboratory, either manual or computer controlled, there will often be problems with the operation of the facility. Troubleshooting may be a time consuming part of the laboratory operation. As the familiarity and experience of the operator increase, the expertise to recognize the nature of problems may increase as well. However, others' expertise can always be used to enrich ourselves in areas such as troubleshooting.

Some interfacing problems may be found in instruments that independently deliver signals to different output devices. The freezing mirror hygrometer, used in the ATCL to measure moisture content in the process air stream, is an example. This instrument shows a digital value on its panel display. Another signal (4 to 20 mA) is taken, preprocessed by the data acquisition program, and then displayed in proper units in the computer monitor. Both displays may show different values due to this independent contribution, requiring the determination of the correct output value.

The implementation of PID loops in software is also difficult. The choice is limited to one or two. The overhead required to operate the PID loops detracts substantially from the time available for data acquisition, scaling to engineering units, data display, operator interaction, and any operational interlocks. Since it is very difficult to properly tune the control loops, auto-tuning controllers were chosen. The selected controllers also accept external setpoints.

CONCLUSION

EPA's Air and Energy Engineering Research Laboratory has designed and built a state-of-the-art research laboratory in response to the need for the evaluation of technologies to control emissions of VOCs and HAPs. This laboratory was designed to be

mostly computer operated under supervision of an operator.

Today's needs of quick response, better controlled operation, and data acquisition from multiple operating parameters have increased the requirement of automated or semi-automated data acquisition and control systems. These systems are designed to control and monitor the operation of complex facilities. When they are used, little or no operator intervention is required.

However, there are some difficulties when data acquisition and control systems are used:

- initially, troubleshooting may be a time consuming part of the laboratory operation;
- interfacing equipment output signals (this may represent a problem if the output signals are independently delivered to several output devices); and
- implementing PID loops with software (this may take much more computer time and engineering skills to properly program and tune the control loops).

The implementation of a PC-based process control and data acquisition system, though not trivial, is a viable solution for research laboratory systems.

REFERENCES

1. C.M. Nunez, M. Kosusko, and B. Daniel, Effect of Humidity on Carbon Adsorption Performance in Removing Organics from Contaminated Air Streams. To be presented at the Air and Waste Management Association meeting in Anaheim, California, 1989.

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